# THE STRUCTURE OF THE GNEISS DOMES NEAR BALTIMORE, MARYLAND

*A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy*

BY

CARL H. BROEDEL

1935

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# THE STRUCTURE OF THE GNEISS DOMES NEAR BALTIMORE, MARYLAND

## INTRODUCTION

### Location and Size of the Area

The area under investigation is situated within the eastern portion of the Piedmont Province of Maryland. In a lenticular shaped area of schist extending from Washington northeastward to the Pennsylvania line occur six dome-like areas of Baltimore gneiss to which the writer will refer as the Phoenix, Texas, Towson, Baltimore, Chattolanee, and Woodstock domes. The schist area is about 18 miles wide in its central portion and narrows to the southwest and northeast. It is the eastern, more highly metamorphosed facies of a large major syncline, the axis of which is occupied by a younger, less metamorphosed series. To the west of this synclinal axis is the western less metamorphosed facies of schist. The gneiss domes are normally surrounded by a thin rim of Setters quartzite (pl. XXVII, in pocket). The writer has examined the domes proper, the intervening synclines of marble and schist were not investigated. The domes and the adjacent synclines and anticlines cover an area of approximately 130 square miles.

The axes of the domes trend northeast-southwest, extending from the easternmost portion of Harford County through Baltimore County, where they are largest, and thence across Howard County almost to the Montgomery County line. Eighteen miles northeast of Baltimore are four lenticular areas of gneiss which are correlated with the gneiss of the domes. These differ from the domes both in shape and the lack of bordering crystalline sediments and hence were considered outside the scope of this investigation.

### Relief and Exposures

The Piedmont gradually rises from the fall line to the west and northwest and the main drainage is southeastward into the Chesapeake Bay. The difference in elevation is from 100 feet in the southeastern portion of the area to 600 feet in the northwest. The highest portion of the area is an old peneplain (Schooley peneplain) which rises westward. The Patapsco River, Gwynns Falls, Jones Falls, and Gunpowder Falls transect

the domes and have entrenched themselves in the crystalline rocks of the Piedmont, forming deep valleys which provide good exposures. Tributary streams which have considerable gradients for a short distance from the main rivers have cut through the residual soil into the crystallines. Farther from the main rivers and towards the central portion of the domes the gradient becomes slight and the streams smaller, yielding only poor exposures and slight relief. The greater part of the area is gently rolling farm country with a relatively thin cover of residual soil and only occasional weathered outcrops. The Little and Middle Patuxent rivers in Howard County have entrenched themselves in the southeastern portion of the Woodstock uplift, providing locally fair exposures, while the same rivers in the central and western portions of the uplift form shallow valleys. The domes stand out relatively high with respect to the synclinal areas underlain by marble which normally surrounds and overlies both the gneiss and quartzite around the borders of the domes. This is due to the fact that the domes, which consist of a core of pre-Cambrian gneiss are normally surrounded by a resistant quartzite. It often forms wooded ridges or slopes around the periphery of the domes protecting the gneiss cores from denudation.

The best exposures in the area are afforded by numerous quarries and railroad cuts. Other exposures were confined to the larger entrenched river valleys, smaller stream beds with sufficient gradient, and road cuts.

## PREVIOUS WORK IN THE REGION

The region about Baltimore was first studied by G. H. Williams (104–110). He divided the Piedmont of Maryland into two areas: an older eastern holocrystalline and a younger western semicrystalline area. This division was based on the greater degree of metamorphism and restriction of intrusives to the eastern area. A stratigraphic sequence had not yet been worked out.

In 1893–94 a detailed report on the granites of Maryland was made by Charles R. Keyes (60) accompanied by a summary of the relations of the granites by G. H. Williams (104).

Between 1894–1907 Edward B. Mathews, assisted by W. J. Miller, studied the structures of the Piedmont near Baltimore. A stratigraphic sequence was established and the schist was found to be the youngest sedimentary formation. An unconformity was recognized between the basal gneiss and the overlying quartzite, marble, and schist (73, 76). In 1905 he compared the sedimentary formations of the Baltimore region with similar deposits believed to be of lower Paleozoic age in southern Pennsylvania. He considered the basal gneiss (Baltimore gneiss) as pre-Cambrian and the overlying quartzite, marble, and schist as Cambro-

Ordovician. In the same year Mathews and W. J. Miller (75) published a summary of their work on the general structure in the dome area of Baltimore County. Detailed descriptions were given of the structure in the vicinity of a fault which crosses the county in its central portion in a northerly direction. W. J. Miller (80) made a detailed study of the stratigraphy and structure of the marble areas of Baltimore County.

In 1907 Mathews (73) pointed out the marked swing of the domes into an east-west trend near Baltimore occurring at a focal point of the great Appalachian swing farther west.

In 1923 E. B. Knopf and A. I. Jonas (66) described the crystalline schists of Baltimore County. The quartzite, marble, and schist were named the Glenarm Series. They concluded that the Glenarm Series was pre-Cambrian on the basis of structural relations in southern Pennsylvania and on the presence of metamorphosed lava flows interbedded in the schists, which they consider as probably equivalent to the pre-Cambrian Catoctin basal complex.

In 1929 Knopf and Jonas (64) gave an account of the rocks of Baltimore County with age relations and petrographic descriptions accompanied by a map of the areal geology. All the crystalline rocks of the county were considered pre-Cambrian except the younger granites and diabase dikes. The Baltimore gneiss is believed to be Archean and the unconformable Glenarm Series Algonkian. They state that the typical, even-banded Baltimore gneiss is sedimentary.

The pegmatites in the crystallines near Baltimore were described by E. H. Watson 102).

In 1933 E. Cloos (28) investigated the flow structure of the Ellicott City granite. Recently C. J. Cohen examined in detail the structures of the gabbro mass at Baltimore (see Part V of this volume).

## GENERAL GEOLOGY AND PETROGRAPHY

### Structural Axes

The structural axes emphasized by the domes trend northeasterly, parallel to the Piedmont and Appalachian structure. In the vicinity of Baltimore they swing into an east-west direction. Four anticlinal axes are evident. They are, from northeast to southwest: the Phoenix anticline, the Caves-Texas anticline, the Woodstock-Chattolanee-Towson anticline, and the Baltimore anticline (fig. 17). The Caves-Texas anticline is a small dome of marble 2 miles north of Chattolanee. The Baltimore dome lies directly west of Baltimore City. The Phoenix and Caves-Texas anticlinal axes both strike N 65° E. The longest of these axes is the Woodstock-Chattolanee-Towson axis which forms an open double curve. In the Woodstock uplift the general trend is N 25° E; in the Chattolanee

and western half of the Towson domes the trend is from E–W to N 70° W, while the eastern half of the Towson dome swings into a northeast trend. The axis of the Baltimore dome also trends N. E. but at its northern end swings into a northwest direction.

Two structures which appear to be cross folds transect the anticlinal axes. They form one saddle between the Woodstock and Chattolanee domes and another one which trends northward from Mount Washington to Cockeysville.

The arrangement of the Woodstock, the Chattolanee, the western half of the Towson and Baltimore domes about the Baltimore gabbro is un-

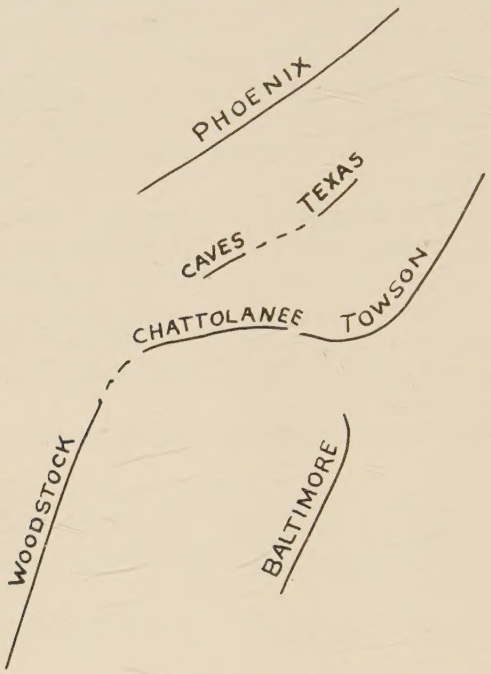


FIG. 17.—Trend of the anticlinical axes of Baltimore gneiss domes in Maryland.

usual. The trend of these domes is older than the emplacement of the gabbro. The gabbro seems to have fitted this synclinal depression within the borders of these domes (see Part V of this volume).

## DISTRIBUTION OF THE ROCK TYPES IN RELATION TO THE ANTICLINAL STRUCTURES*

### THE BALTIMORE GNEISS COMPLEX

The cores of the domes are composed of an intimately banded gneissic complex principally of four types. The larger portion of the complex

* For detailed information and localities not shown on plates XXVII–XXXII see geologic map of Baltimore County.

varies from a heavily banded granitoid biotite gneiss to a thinly layered ribbon gneiss (Baltimore gneiss). Interbanded and concordant with the Baltimore gneiss is an augen gneiss (Hartley augen gneiss), which seems to be confined chiefly to the periphery or upper portion of the gneiss cores, although exceptions do occur. The third type is a hornblende gneiss or amphibolite which, like the augen gneiss, is interbanded with the Baltimore gneiss. The bands are from one foot to many feet thick. No regularity in the distribution was observed with respect to the gneiss cores. They are, however, restricted to certain zones. Several zones occur along the Patapsco River for 2 miles in the vicinity of Woodstock. They are common throughout the Baltimore dome and locally in the northwest portion of the Towson dome. The fourth type is a medium grained gneissic granite (Gunpowder granite). It intrudes and injects all of the previous three types as well as the lower Glenarm formations with which it is generally concordant. This granite is difficult to distinguish from the granitoid facies of the Baltimore gneiss, so that only an approximation can be made in regard to its distribution. It is most typically developed in the eastern portion of the Towson dome and occupies a large portion of the Texas dome although here the granite is difficult to distinguish from the Baltimore gneiss. Thin stringers and bands apparently equivalent to this orthogneiss inject the Baltimore gneiss throughout the western portion of the Towson and eastern part of the Chattolanee domes.

Between the Baltimore gneiss complex and the Glenarm Series is a major unconformity. Both stratigraphically and structurally it is an important boundary and will be used in the following text as a datum plane.

### THE SETTERS FORMATION

The distribution of the Setters formation is closely related to the shape of the gneiss cores of the domes and associated anticlines normally surrounding them as a narrow rim except locally if it is missing. This formation in its most typical development is composed of three members: a lower mica schist member, a middle quartzite or mica gneiss member, and an upper mica schist member. This threefold division can not always be recognized. Quartzite may dominate the formation in some localities while mica schist may prevail in others. Again, the quartzite member may be replaced by a series of alternating beds of mica schist and quartzite. In general the quartzite is the most characteristic member and forms an excellent guide horizon. Due to its high resistance against weathering as compared with the gneiss and particularly the Cockeysville marble, it frequently forms prominent ridges around the gneiss domes in the more dissected areas.

The Setters formation is exposed as a continuous rim along the northern

flank of the *Towson dome* except one-half mile southeast of Oakleigh where it is locally missing or very thin. Along the western end of the dome it is cut out by a prominent fault between Riderwood and Mount Washington (Ruxton fault). Along the southeastern flank of the dome relations are obscured by Coastal Plain sediments. The Setters formation is continuous from the sharply compressed nose near Hartley southwestward to Cub Hill. On the north side of Gunpowder Falls it is intruded by large amounts of Gunpowder granite. Its continuation southwestward to Herring Run where it is again exposed is likely since typical quartzite fragments were found several hundred yards north of Putty Hill Road, 1.4 mile west of the Harford Road. That a closure exists around the southern nose of the dome south of Lake Montebello is indicated by a convergence in strike and new exposures along Lock Raven Boulevard.

The gneiss core of the *Texas dome* is flanked by the Setters formation on its north, east, and southeast sides. Along the southern border of the dome it apparently lenses out at the Pots Spring Road, while along the entire western side it is cut out by a fault. At the south end of the dome it forms a large mass, probably the result of local folding, while along the eastern flank at Pots Spring Road it becomes very thin. The quartzite member is poorly developed except at the north end of the dome. The larger portion of the formation is mica schist with occasional quartzite beds. A highly garnetiferous mica schist forms the upper part of the formation.

The *Chattolanee dome* is surrounded by a continuous rim of the Setters formation except where it is locally cut out by fault breccias along the southern flank. Here two quartzite ridges branch off from the dome and thin rapidly eastward. At Mount Wilson the Setters formation forms two parallel ridges, the limbs of an infolded syncline. The western half of the north limb is largely brecciated while the south limb is locally confused with Wissahickon schist.

The Setters formation is largely missing around the *Baltimore dome.* It occurs only along the northwestern flank of the dome between Gwynns Falls and Hampden where it is largely developed as a mica schist. It is apparently cut out at both ends by an igneous intrusive (Relay quartz diorite).

It forms a continuous rim around the *Woodstock* and associated anticlines (pl. XXVIII, in pocket) with the exception of the southeastern flank of the anticlinorium. Here, due to the lack of exposures and confusion with the Wissahickon schist, its continuity is uncertain. However, along the middle Patuxent River where a typical section is exposed and near Dorseys Run the presence of quartzite was sufficient to establish it at least locally. In the vicinity of Rockland, Howard County, it is very thin and apparently discontinuous.

Around the *Phoenix dome* and associated synclines the distribution of the Setters formation is irregular, frequently thinning or pinching out. It is locally absent near Monkton and Dover and along the southwest flank of the dome. It is also largely missing along the flanks of a large syncline infolded into the northwestern portion of the dome.

### THE COCKEYSVILLE MARBLE

The Cockeysville marble is a medium to coarse-grained marble frequently interbedded with dolomitic layers. Locally calcareous mica schist facies are developed. It is the least resistant of the rocks in the region and forms characteristic valleys. The marble has its greatest development in the northern half of the area especially in the broad synclinal area which lies between the Phoenix dome on the north and the Chattolanee and Towson domes on the south. The marble is irregular in distribution throughout this syncline, probably because it lies at a relatively shallow level and where slight uplift has taken place broad valleys have been formed. In the southern half of the area, where structures have been more deeply folded, the marble is restricted areally and frequently lacking. It appears in narrow valleys surrounding the Setters formation.

Marble accompanies the northern border of the Towson dome from Greenwood along the southeastern flank, where it is apparently thrust out, to Hollins Station along the western end where it is cut out by a fault. Along the southwestern flank between Govans and Lake Montebello the presence of marble has been indicated by the character of the water and proven through excavations for the city water tunnel.

It is possible that the marble completely surrounds the Chattolanee dome although its continuation along the southern flank is somewhat uncertain. In the vicinity of Pikesville and south of Horsehead Branch along the western margin of the uplift there is some doubt as to its presence, but locally it is indicated by valleys. It occurs in three narrow valleys which flank the two anticlinal arms or slivers of quartzite along the southeastern border of the dome. Again, at Mount Wilson it occurs in a syncline of the Setters formation about three miles long.

In the Woodstock anticlinorium the marble is irregularly distributed and apparently discontinuous. It normally surrounds the Woodstock dome and associated anticlines, forming narrow valleys around the Setters formation. Marble occurs along the entire northern and western margin of the anticlinorium while it appears to be missing along the entire western margin, except for a narrow strip between Rockland and Alberton. It is most extensively developed in a shallow syncline west of Clarksville, while farther to the north it plunges under a syncline of Wissahickon

schist, forming narrow valleys along the limbs of two synclines which lie along the southeast side of the Woodstock dome. It seems to be largely missing along the limbs of the overturned anticlines and synclines lying southeast of the dome. Marble is developed locally in the complicated structures near Alberton, in the syncline near Davis, at Jew Bottom ($\frac{3}{4}$ mile northwest of Alberton) along the south limb of a narrow anticline which may be called the Jew Bottom anticline, and for a short distance along the western flank of the Bens Run anticline.

Marble almost completely surrounds the Texas dome with the exception of the northwest side where it has been cut out by a fault. It surrounds the Phoenix dome except along its northeast and southeast flanks where it is locally missing. It attains its largest development in the broad syncline within the northwestern portion of the dome.

### THE WISSAHICKON FORMATION

The Wissahickon formation is the youngest formation of the Glenarm Series encountered in the area occupied by the domes. It has been called the Wissahickon oligoclase mica schist to distinguish it from its western less metamorphosed facies. It is composed largely of mica schist and mica gneiss interbedded with quartzite. This formation has a larger areal extent than any of the preceding formations and occupies the greater part of the synclinal areas between the domes. It is confined chiefly to the northern and western portions of the area, while in the northeastern portion it is either covered or cut out by large igneous intrusions.

The Wissahickon schist completely surrounds the Woodstock anticlinorium as well as the Phoenix and Chattolanee domes, except in the vicinity of Cockeysville and Brooklandville respectively. This appears to be due to slight uplift in those two localities accompanied by removal of the schist. It surrounds the eastern half of the Towson dome from Oakleigh to Lake Montebello, forming a narrow strip along the entire southeastern flank. In the Woodstock anticlinorium the schist is confined to narrow synclines associated with the Woodstock dome.

### THE PEGMATITES

Both conformable and cross-cutting pegmatite dikes occur throughout the gneiss complex and overlying crystalline formations although the larger dikes appear to be confined to certain areas. Pegmatites vary in size from small stringers and isolated lenses to large dikes several hundred feet wide and a mile or two long. The larger pegmatite veins generally occur as dike swarms and conform to the local strike of formations. They

seem to be most abundant along the flanks of the domes and anticlines as well as within synclines or at contacts. Pegmatite dikes are particularly abundant in the easily permeable mica schist of both the Setters and Wissahickon formations which have lent themselves to pegmatitic solutions. Here the dikes formed are nearly always concordant. They appear to be lenticular bodies having spread apart the schist on both sides.

Pegmatites are most abundant in the Baltimore dome and synclinal structures southeast of the Woodstock dome. In the Baltimore dome a series of large pegmatites occur in the gneiss along Gwynns Falls between its western limb and Claremont. These are largely conformable and in the southern portion are highly schistose. Smaller dikes, stringers, and offshoots from the larger dikes are frequently cross-cutting. Large dikes occur along the contact of the Setters mica schist with both the gneiss and quartz diorite. Swarms of large dikes have injected the mica schist south of Hampden.

Many large and small pegmatites have intruded and injected the synclines and limbs of anticlines between Hollofield and Davis. They are most abundant in the Wissahickon schist and marble and to a less extent in the gneiss and quartzite. A swarm of large dikes follows the eastern flank of the anticlinorium from Rockland northward for three miles. Another swarm occurs in a syncline which swings around the north end of the anticline at Alberton and parallels the north side of the Patapsco River to the vicinity of Davis where it crosses the river in a northwesterly direction (Davis syncline). East of Rockland and Alberton large pegmatite dikes follow the contact between the Baltimore gneiss and Setters formation. A few pegmatite dikes occur within the gneiss core of the Woodstock dome, but these are mostly small. Several large dikes intrude the Wissahickon schist and marble along the northwest border of the dome between the north and south branches of the Patapsco River. In the southern half of the anticlinorium large pegmatites are not common. Several dikes intrude schist and marble in a syncline which extends southward to Clarksville, as well as the gneiss along the western border of the adjacent anticline on the east. Also in the schist along the southeastern flank of the anticlinorium pegmatites are common.

In the Towson dome pegmatites are largely confined to the flanks. A swarm of dikes occurs in the marble and schist along its northwestern limb between Cromwell Bridge and Glenarm. Large pegmatite dikes are not common within the gneiss complex although smaller stringers and lenses are abundant. Two dikes follow the contact between augen gneiss and the Setters formation along the north flank of the dome near Oakleigh and at Gunpowder Falls.

No large pegmatites are associated with the Chattolanee dome, although

small stringers and lenses are common. In the Texas dome they are also lacking, although several inject the Setters mica schist along the south side.

### THE ALASKITE-PORPHYRY DIKES

A number of alaskite porphyry dikes up to several feet wide cut the marble and schist between Hollofield and Dorseys Run. Locally they conform to the strike of the country rock. The largest dike cuts across the strike of the schist along the northeast limb of the Alberton anticline one-half mile east of Alberton and strikes N 20° E. Along the south side of the Patapsco River one-half mile southwest of Alberton two dikes intrude the marble and contact between marble and Setters formation. They strike northeast and cut across the strike of the country rock. Along the north side of the river, one-half mile northeast of Alberton, 9 large dikes and several smaller ones cut the schist, although several appear to be locally conformable.

### THE DIABASE DIKES

A belt of one or more diabase dikes crosses the western part of the area in a north to northeast direction (Plates XXX). It follows the southeastern flank of the Woodstock dome near Dorseys Run, crosses the eastern half of the Woodstock dome and western end of the Chattolanee dome where it appears as two dikes, although these may be connected. Farther north it has been traced as a single dike across the northwestern portion of the Phoenix dome. These dikes have no relation to the domes and clearly cut across all structures. In the vicinity of Dorseys Run evidence of five dikes was found within a distance of one and a half miles and in the northeastern portion of the Woodstock dome there appear to be two dikes. The dikes are rarely exposed, their presence being indicated by scattered boulders which can only be traced for a short distance along the strike. It is possible that some of them may be connected.

### FAULT BRECCIA

Breccia occurs at a number of places throughout the area, principally along the periphery of the domes. It is most typically developed along the Ruxton fault between Mount Washington and Warren. It is exposed at the southern end of Lake Roland and occurs along the west side of the Texas dome for two miles. In the Chattolanee dome breccias occur locally along the south side. Along the southeastern flank two breccias occur between the gneiss and quartzite, one of them one and a quarter miles southwest of Rockland and the other a mile and a quarter farther

west. The western portion of the north limb of the syncline at Mount Wilson is largely brecciated. The only definite evidence of brecciation in the Woodstock anticlinorium is a local occurrence on the south limb of the Jew Bottom anticline, ¾ mile east of Davis. Breccia also occurs along the limbs of a syncline infolded into the southeastern portion of the Woodstock dome, but those are of a different type and may be brecciated and leached igneous rocks (see Plates XXXI).

### Relation of Granite and Gabbro Intrusions to the Domes

In general the granites appear to have intruded the domes and associated anticlines while the gabbros and associated basic rocks have sought the synclinal areas, as is shown in many other crystalline terranes. This generalization holds good for the basic intrusives but does not cover all the granitic rocks, large bodies of which have intruded and injected the schist along structural boundaries or as isolated lenticular bodies within the gabbro areas.

The granitic rocks may be divided into older granite gneisses and younger granites. The former are confined to the eastern portion and the latter to the western portion of the area. The granite gneisses have intruded and injected the Baltimore gneiss in the Texas dome and eastern portion of the Towson dome. They occur in the gabbro belt of the Texas dome as well as within the Baltimore gabbro. A gneissic quartz diorite forms a long sill-like body between the Baltimore gabbro and the Baltimore gneiss along the north side of the Baltimore dome. Among the younger granites which have intruded the Baltimore gneiss are the intrusive in the center of the Woodstock dome and smaller bodies in the anticlines to the southeast. Among those in the schist are the octopus-like intrusion at Ellicott City (26) along the southwestern contact of the Baltimore gabbro and a large series of intrusions and injections which follow the entire southeastern border of the Woodstock dome and associated anticlines and synclines (Woodstock anticlinorium).

The basic rocks including gabbro and serpentine are confined to three main zones: an eastern belt which follows the southeastern border of the Towson dome, a large central mass occupied by the Baltimore gabbro (see pt. V), and a western belt which follows the western border of the Woodstock anticlinorium and the northwestern flank of the Phoenix dome. Other small dikes of serpentine occur in minor synclines of schist associated with the domes, as, for example, the dike along the western flank of the Bens Run anticline. The eastern and western belts of basic rocks mark the eastern and western boundaries of the Maryland domes. The former belt of gabbro occupies a synclinal area of the schist into which a series of

anticlines or slivers of Baltimore gneiss have been upfolded or upthrust near Belair. The western belt occurs along the western border of the eastern facies of the Wissahickon synclinorium and lies directly east of the Peach Bottom syncline which marks the axis of this synclinorium.

### UNCONFORMITY BETWEEN THE BALTIMORE GNEISS AND THE SETTERS FORMATION

An unconformity between the Baltimore gneiss and Setters quartzite, the lowest formation of the Glenarm Series, has been recognized by all who have studied the Piedmont of Maryland. The unconformity in

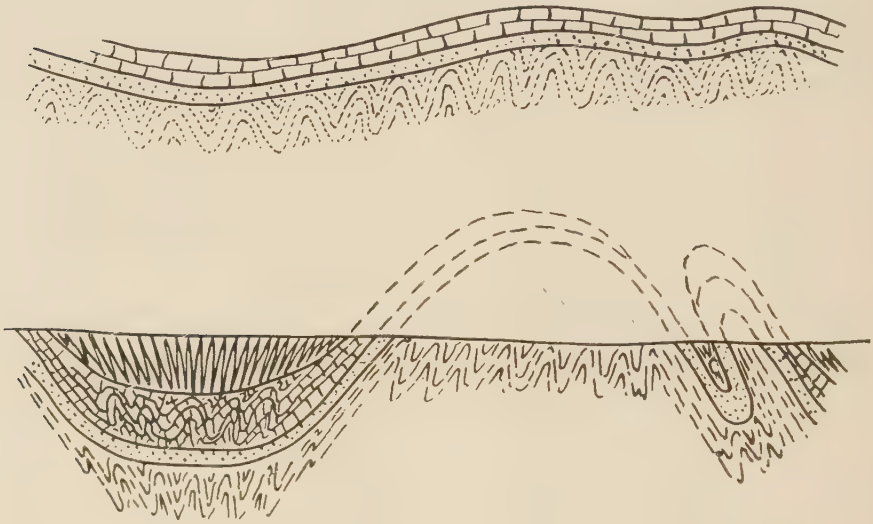

FIG. 18.—Diagram showing obliteration of the unconformity along the flanks of domes and the types of folding.

Maryland has been largely obliterated by intense folding during the uplift of the domes. The best evidence for a general unconformity is shown by the much greater deformation and igneous injection in the gneiss as compared with the Glenarm Series. In addition the Hartley augen gneiss and the hornblende gneiss, which occur in the Baltimore gneiss, are absent in the Setters and overlying formations. In contrast to the gneiss with its high degree of minor isoclinal folding and its ptygmatic folds, the quartzite is relatively free from such minor folds except locally. It was protected by and folded along with the old gneiss surface during post-Glenarm deformation.

Knopf and Jonas (64) point out a divergence in strike of 20 degrees between the gneiss and quartzite as evidence for an unconformity. To

the writer this appears to be insufficient evidence, since the foliation of the gneiss and the bedding of the quartzite often vary considerably in strike as a result of minor folding even within a short distance of the contact. Where contacts are exposed they are always conformable.

One would expect to find evidence of an unconformity on the crests of domes or anticlines where the quartzite lies flat upon the gneiss but such contacts have either been eroded or are not exposed. The sharp nose of domes and anticlines were also investigated, but exposures at such critical points were either lacking or insufficient to determine an angular unconformity. On the other hand, the general strike and dip of the gneiss foliation, wherever observed along the blunt ends of the domes, was largely conformable to that of the quartzite.

## METHOD OF STUDY

The domes near Baltimore are unique elements in the structure of the Piedmont. Their circular-to-oval outline distinguishes them from other similar uplifts to the northeast in Pennsylvania, New Jersey, and southeastern New York, which are anticlinal rather than dome-like. Anticlines and synclines associated with a single dome were found to be overturned in different directions and this leads to a complicated problem as to the type of deformation which produced such structures. The region as a whole is poorly exposed, formations are unfossiliferous and often difficult to distinguish from one another; and sudden thinning or lensing out of formations along the strike occurs in many places. Overlaps, occasional unconformities, igneous intrusion, faults and overthrusts may be responsible for the apparent local absence of formations.

A study of the best exposed profile and most complicated structure in the region was undertaken. The writer spent the summer of 1933 making a detailed map along the Patapsco River from Hollofield to Marriottsville. A section about one mile wide was mapped in detail on a scale of 200 feet to the inch. Later the study was extended to the domes as a whole and the associated anticlines and synclines. The Towson, Baltimore, and Chattolanee domes were surveyed during the fall of 1933 and spring of 1934. The summer of 1934 was spent in the westernmost uplift known as the Woodstock anticlinorium. Two weeks were spent in the granite intrusives in the Woodstock dome. An attempt has been made to determine whether or not structures in the granite conformed to those in the surrounding country rock. Occasional field trips were continued throughout the fall of 1934 in studying the Texas dome. The Phoenix dome was mapped during the summer of 1935.

In such a highly folded region as the Piedmont of Maryland large numbers of measurements must be taken in order to obtain a picture of

the structure. All available structural elements were measured in an attempt to ascertain the trend or pattern of these elements with respect to the general outline of the domes. The structures measured were linear elements such as axes of folds and crinkling (see Part I of this volume), parallelism of minerals and grooving on foliation and bedding planes (linear stretching), and slickensides. Platy elements measured include bedding, foliation, joints, cleavage, and axial planes of folds. It was not possible to obtain sufficient readings on slickensides and axial planes to draw any conclusions from them. Particular attention was paid to linear parallelism, axes of folds, and cross joints since these were found to be most useful in interpreting the structures. The strike and dip of foliation and bedding was found to vary considerably within any one locality; this is to be expected in a highly folded region. Therefore large numbers of measurements were taken in order to obtain average values. Likewise, thousands of readings of linear structures and joints were taken because linear structures such as linear parallelism and axes of folding were often exceedingly irregular both in strike and pitch especially in the gneiss.

During the earlier field work joints were measured at random throughout the domes and appeared to be highly irregular, but in the east-west trending structures prominent systems of cross-joints were noted. Large numbers of joints were needed at well exposed points throughout the area for the determination of the major joint systems. A statistical counting of joints in the gneiss, quartzite, and marble was therefore made in 25 quarries and well exposed localities.

Over 3500 measurements were taken of bedding, foliation, joints, linear structures, and other elements. In addition about 3000 joints were read and counted in quarries and plotted on joint diagrams (figs. 19–26).

A Breithaupt compass graduated in 360° was used in the field work. All readings of strike were read in terms of 180°, north being 0 or 180°, northeast 45°, east-west 90°, and northwest 135°. This method of recording was both simple and time saving and found to be very satisfactory when large numbers of measurements are to be made. In the descriptive portion of the text as well as in the joint diagrams the writer will refer to strike directions as 45°, 90°, 135°, and 180° respectively.

The areas overlain by Coastal Plain sediments were omitted from the maps since they would only have confused the outlines and structure of the area.

The following were used as base maps: Baltimore and Ohio Railroad right-of-way maps of the Patapsco River section (1 inch = 200 feet), Maryland State Roads Commission maps of Baltimore and Howard counties (2 inches = 1 mile) and the topographic maps of the State Geological Survey (1 inch = 1 mile).

Plates XXVIII and XXX were platted on a scale 2 inches = 1 mile and

reduced to half size. In these maps a large number of readings could not be platted and only averages were used.

Plates XXIX and XXXI were drawn from an enlargement of the topographic maps on a scale of 4 inches = 1 mile, the contour line map (Plate XXVII) being reduced to quarter size and the cross sections (Plate XXXII) to half size.

The contour lines are based on the outcrop of the Setters quartzite and represent its attitude only along the flanks of the uplifts. No attempt was made to reconstruct its entire surface. In plotting the joint diagrams a scale of $\frac{1}{10}$ inch = 1 joint was used. The number of joints at intervals of five degrees were added and plotted between these directions to smooth out irregularities and then reduced to half size.

## REGIONAL DISTRIBUTION OF STRUCTURES

### General Remarks

Soon after the beginning of the investigation it became evident that the unconformity between the gneiss basement and the sedimentary cover (Glenarm Series) was of great importance. The gneiss complex is very closely folded, as shown by frequent reverse dips. Its surface, however, shows a much more open folding and a much less irregular outline. It was recognized that the Setters formation followed this surface closely and is comparatively free from minor folds. On the other hand, the sediments (marble and schist) above the Setters formation are tightly folded and, as a rule, not closely related to the areal distribution of this unconformity. The gneiss surface and the Setters formation seem to represent a twofold unconformity; that is, stratigraphic as well as structural and therefore a plane of great tectonic significance. A contour line map was drawn approximately on the quartzite member of the Setters formation in order to show the shape and configuration of this plane (Plate XXVII).

Because of the significance this plane of unconformity was used as a reference plane in the following and an attempt was made to consider the different structures in relation to it.

### Structures Below the Unconformity

#### internal structures of the gneiss domes

*Arrangement of banding, linear parallelism, and axes of folding*

The internal structure of the gneiss domes is dominated by primary elements. The banding, associated with and perhaps in part caused by the intrusion of granitic material into sediments, is undoubtedly older

than the unconformity which truncated these structures in a more or less horizontal plane. Later movements and deformations have modified and altered the position of these primary structures. The present arrangement permits a reconstruction of their original attitude. The later and superposed deformation, which also affected the unconformity, can to a certain extent be reconstructed through a consideration of that reference plane.

The question arises: how the presence of these early primary structures affected the formation and shape of the later domes, in other words, the deformation of the unconformity. Did the gneiss possess a structure which facilitated the uplift of the domes and was accentuated by it, or is the structure of the gneiss domes entirely the result of later deformation which took place after the deposition of the Glenarm Series?

The arrangement of primary structures in the gneiss complex can be seen in plates XXVIII–XXXI. Three types of arrangement can be recognized, although combinations do occur: *linear* in which the elements strike parallel to the longest axis of the uplift, *circular* in which the elements parallel the flanks of round domes, and *transgressing*, the strike of the axes of folding and linear parallelism transgresses the axis of uplift and strike of banding.

*Linear arrangement.*—The strike of banding in the Phoenix, Towson, and Chattolanee domes and the southern half of the Woodstock anticlinorium parallels the axes of uplift, except at the blunter ends where it seems to "run around." At the sharper noses it seems likely that the banding maintains its strike. In general, where the domes are narrow and the gneissic bands dip vertical the strike of banding closely follows the axes; as for instance, in the eastern and western portions of the Towson dome and in the Chattolanee dome (Plate XXIX). Because of the gentle dip of banding in the central portions of these domes the strike is not shown.

Throughout the major portion of the Towson dome, except in its south-central part, banding parallels the axes of uplift. In its southern termination it follows the periphery of the dome. Banding is prevailingly steep to vertical and along the periphery generally dips outward from the center of the dome. There is evidence that banding along the entire southeastern border dips northwest, except in the vicinity of Long Green Creek (Plate XXXII sections 1 and 2). In the western portion of the dome banding maintains its east-west trend up to the Ruxton fault where it is truncated at a high angle (Plate XXIX and Plate XXXII section 3).

Along the north and south sides of the Chattolanee dome banding dips away from the complex or is vertical as along the north side. Along the east end more gentle dips prevail (Plate XXXII sections 4–7). The

dome-like representation of banding in sections 4 and 5 is generalized from a number of very gentle dips.

In the southern half of the Woodstock anticlinorium throughout a long V-shaped anticlinal structure, extending from Mayfield southward to Highland and thence southeastward through Dorseys Run to Alberton, banding parallels the axes of uplift except along the periphery of its southern end where it runs around. This anticlinal structure will be referred to as the Mayfield-Highland and Highland-Alberton anticlines (Plate XXVIII). There is a general overturning of the gneiss toward the east from Alpha and Pine Orchard on the north to Highland and Fulton on the south of these anticlines. This overturning is more pronounced in the Mayfield-Highland anticline where very gentle dips are common (Plate XXXII, sections 12–14).

Axes of folding and linear stretching are largely parallel to the long axes of these domes. At the ends of the domes (noses) these linear structures plunge gently but retain their strike. These noses can be rather sharp (east ends of the Towson and Phoenix domes) or comparatively blunt, as the east end of the Chattolanee dome and southern end of the Woodstock anticlinorium.

The northeast end of the Towson dome is the most striking example of a sharply compressed plunging anticline. The Towson dome narrows down from a maximum width of 5 miles in its central portion to one-half mile at Long Green Creek. Three-quarters of a mile to the northeast it is only a few hundred feet wide.

The eastern end of the Phoenix dome resembles somewhat that of the Towson dome and has been likened by some observers to the prow of a boat. Similar sharp noses are seen at the southeastern termination of the Woodstock anticlinorium near Fulton and at the northern end of the Mayfield-Highland anticline.

Linear stretching in the Towson and Chattolanee domes seem directly connected, indicating the close structural relationship between the two. Linear parallelism and axes of folding follow the axes of these domes and plunge gently at their ends. The Chattolanee dome is the simpler of the two. Linear structures throughout the central portion of the dome are approximately horizontal. Along the eastern end they show a marked bend toward the Towson dome and pitch 10 to 30 degrees east (Plate XXXI). The Towson dome, on the other hand, does not show a simple dome-like arrangement of linear structures. Throughout the major portion of the dome from Cromwell Bridge to the Ruxton fault they pitch prevailingly westward 10 to 45 degrees. At Gunpowder Falls they are roughly horizontal and at Long Green the pitch becomes eastward. Where the westward pitch of linear elements becomes marked there is an increase in the width of the dome and the axes spread apart. They closely conform

to the axes of the dome, except in its southern termination where they trend across the southwestern flank and pitch 10 to 25 degrees southwest (Plate XXXI).

Throughout the western two-thirds of the Phoenix dome linear structures pitch gently to moderately westward (10 to 40 degrees). Within the eastern one-third of the dome the axes plunge gently eastward. This arrangement is very similar to that in the Towson dome.

In the southern half of the Woodstock anticlinorium linear structures closely parallel the axes of uplift. Gentle to undulating pitches prevail and frequently they are horizontal. In many localities the strike of the axes of folding is rather irregular, pitching gently to moderately both northeastward and southwestward. Linear parallelism at the northern end of the Mayfield-Highland anticline seems to transect the uplift axis, pitching 20 to 25 degrees southwest (Plate XXX). Between Nichols and Fulton linear structures trend across the southwestern flank of the anticlinorium, pitching south 5 to 20 degrees. In the vicinity of Dorseys Run they are roughly horizontal while between Rockland, Howard County, and Alberton they plunge gently to steeply east (Plate XXX).

*Circular arrangement.*—Structures of this type are principally different from the linear arrangements and include the Texas dome and the eastern half of the Woodstock dome. The western half of the latter dome might be considered under transgressing arrangements below.

The linear as well as platy elements (banding) are bent into a semicircle following the periphery of the domes. The arrangement of structure is broad and more open. The ends of these domes are also broad and a horizontal section through the domes is more or less circular.

Banding in the Woodstock dome (Plate XXVIII) forms a roughly circular trend across the Woodstock granite intrusive. Along the periphery of the dome banding dips moderately to steeply away from the gneiss, except along its southeastern flank where it is overturned to the southeast and south. The banding converges toward the southern end of the dome where it forms a sharp nose. Throughout the southwestern half of the dome banding dips prevailingly westward (25 to 90 degrees) (Plate XXXII, section 11).

The trend of linear structures forms a semicircular arrangement in the eastern half of the dome, while in the western half they diverge slightly toward the west (Plate XXX). The eastern half of the dome is a typical example of circular arrangement of structure. East of Granite they are roughly horizontal. Along the northeastern periphery of the dome they parallel the banding and show a persistent north to northwest pitch (10 to 45 degrees). Throughout the western half of the dome they transect the strike of the banding and maintain a persistent west to southwest plunge (5 to 40 degrees).

The Texas dome seems to be only a half dome because its western continuation has been faulted out. The eastern preserved portion is very similar to the eastern half of the Woodstock dome. Here the banding as well as linear elements form a semicircle and the shape of this dome is also broad and the eastern termination blunt.

Banding (Plate XXIX) bends around from an east-west trend in the southern portion of the dome to northwest in its northern portion. At the northeastern end the gneiss forms a sharp little nose which plunges gently under the Setters formation. Along the eastern side at Pots Spring Road the gneiss is slightly overturned to the east. The banding is truncated along the west side by the northern continuation of the Ruxton fault.

The trend of linear elements is much more regular (Plate XXXI). From a north-south strike and roughly horizontal position along the eastern side of the dome, they swing into a northwest strike and gentle northwest pitch at the northern end of the dome and into a northeast-southwest to east-west strike and westerly plunge (10 to 45 degrees) in the southern portion. Reverse pitches are found locally.

*Transgressing arrangements.*—Under this type are included uplifts in which the linear structures plunge down the dip of banding comparable to the arrangement of linear parallelism in the Böllsteiner gneiss described by H. Scholtz. This is, however, not a distinct type but a combination of types of which the Baltimore dome is the most typical. Here the banding trends roughly northeast, except at the northern end of the dome where it swings into a northwest direction along with the axis of uplift (Plate XXIX). Here the gneiss is probably truncated by the Relay quartz diorite. The gneiss dips prevailingly westward (20 to 50 degrees), except at the northern end where it dips steeply westward or vertical.

All linear structures trend west to northwest and plunge in the same direction (Plate XXXI). The dip of banding and linear structures coincide only in the northern end of the dome.

The Bens Run anticline may be included here. In this anticline banding trends north-south and dips steeply east to vertical, indicating a slight overturning towards the west (Plate XXXII, section 10). Linear structures, however, strike east to northeast and plunge moderately to steeply in either direction. This arrangement of linear structures seems to be affected by those in the Woodstock dome.

### ARRANGEMENT OF CROSS JOINTS IN RELATION TO AXES OF FOLDING AND LINEAR PARALLELISM

A close relation between linear structures and cross joints becomes evident in Plates XXX and XXXI. Of the many joint systems which are found one direction seems to intersect the linear direction at an angle

of approximately 90 degrees. If the linear direction changes in strike the cross joints roughly follow this change. They were, therefore, emphasized by heavy black lines which indicate their average strike. The direction was generalized in many places, because of local irregularities in the strike of linear elements.

The general interdependence can very well be observed in the distinct change in direction of the cross joints within the Towson dome (Plate XXXI). Between its western and northeastern ends they vary from a northeast-southwest to a northwest-southeast trend, or 66 degrees within six miles. The bend of linear structures and corresponding change in strike of cross joints is coincident with a bend of the northern flank of the dome. The anticlinal axis and linear structures are intersected at an angle of approximately 90 degrees by the joints. They are most prominent in the western and north-central portions of the dome where they dip steeply to vertical. In the northwestern portion of the dome cross joints strike 175 to 15 degrees and dip steeply east (Plate XXXI). Slight changes in the strike of linear structures are accompanied by a corresponding change of cross joints, as at Charles Street and Malvern Avenue where they trend northeastward and dip steeply east. Cross joints are not pronounced in the northeastern and southern portions of the dome. At Cromwell Bridge (fig. 20) they strike north-northeast and dip 65 degrees east. At Gunpowder Falls they strike 135 degrees and dip steeply northeast, while at Long Green Creek cross joints seem to strike north-south and dip vertical. In the southern portion of the dome cross joints with a few exceptions are replaced by a very pronounced east-west striking joint system.

The axis of the Chattolanee dome is straight and the internal structure of this dome is comparatively simple. Linear elements are roughly parallel to its axis and cross joints are perpendicular to both. North-south cross joints dominate over all other joints and generally dip steeply to vertical. At the eastern end of the dome they dip steeply west and swing slightly around to the northeast along with a corresponding bend in linear structures. In the western portion of the dome cross joints are abundant and dip steeply east (pl. XXIII, fig. 1).

The same relation is more conspicuous in the Texas and Woodstock domes. The cross joints have a radial arrangement and remain in a perpendicular relation to the linear structure. As in the Towson dome, cross joints parallel the strike of the Ruxton fault along the western portion of the Texas dome. Along its eastern side they strike east-west, while toward the north and south they swing around into a northeast and southeast direction respectively. The attitude of the joints is somewhat irregular but steep dips prevail.

In the Woodstock dome and associated anticlines relations are more complicated. Cross joints form a fan-like arrangement and appear to radiate northward from an area south of Dorseys Run, always remaining perpendicular to the linear structures. Dips are generally steep westerly to vertical in the eastern half of the dome while in its western half, where linear elements plunge gently westward, cross joints dip steeply east (see Plate XXX). Between Davis and Hollofield cross joints are very pronounced and maintain a north to northeast direction. Near Davis they dip steeply east while in the vicinity of Rockland they dip steeply west.

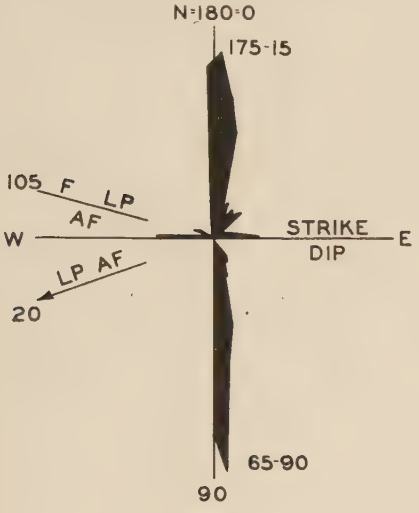


FIG. 19

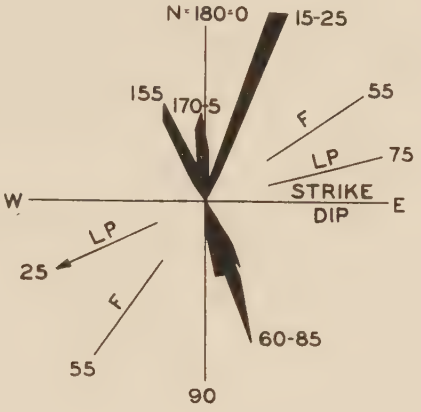


FIG. 20

FIGS. 19-26.—Statistical diagrams of the direction of jointing. B = strike and dip of bedding, LP = strike and pitch of linear structures, AF = strike and pitch of axes of folding, F = foliation.

FIG. 19.—Joints in Baltimore gneiss. Malvern Avenue, near Ruxton.
FIG. 20.—Joints in Baltimore gneiss at Cromwell Bridge.

Relations in the eastern portion of the dome and in the Bens Run anticline are not quite clear.

Throughout the southern half of the anticlinorium cross joints seem to transect the axis of uplift and trend of linear elements. Dips are somewhat irregular but generally steep, varying with the local undulations of the linear structure.

In the Baltimore dome cross joints trend northeastward parallel to the axis of uplift, except at its north end where they transect it. Locally linear structures strike east-west and the cross joints north-south. Throughout the dome they dip moderately to steeply eastward. The relations between

linear parallelism and cross joints is shown in the joint diagram of the Falls Road Stone Quarry near Druid Lake and Gwynns Falls and Hilton quarries south of Edmondson Avenue (figs. 21 and 22). In both cases cross joints form the major system and dip moderately to steeply east.

It is very noticeable that cross joints are more conspicuous, numerous, and closely spaced where they occur within long and narrow domes of anticlinal shape as, for instance, the Chattolanee dome or the narrow anticlines along the southeastern side of the Woodstock dome. Cross joints in roughly circular domes are less distinct as may be expected. In the Texas dome they do not form a dominant system, even where locally quite abundant. In these domes all the joints which appeared to be cross

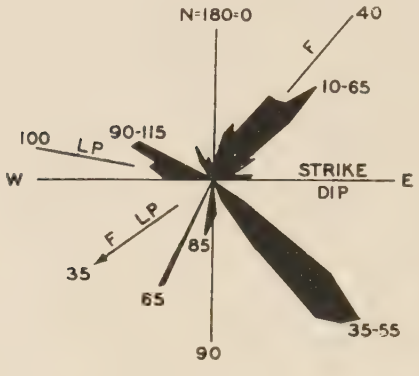


FIG. 21

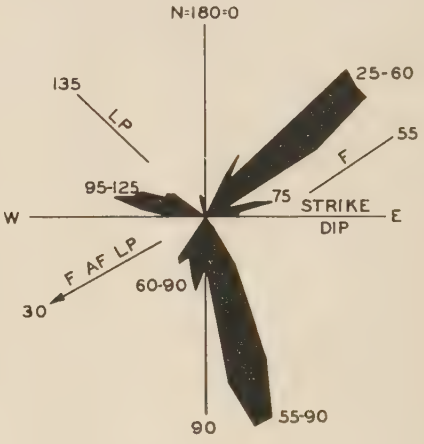


FIG. 22

FIG. 21.—Joints in Baltimore gneiss in the stone quarry at Falls Road.
FIG. 22.—Joints in Baltimore gneiss. Gwynns Falls and Hilton quarries.

joints were measured rather than other joints so that the maps show cross joints as the dominant system, which is actually not the case.

Most of the joints measured in the Phoenix dome vary in strike between 145 and 10 degrees. They trend across the strike of linear structures in a north-northwest direction and seem to be largely cross joints. They are abundant along the Falls Road between Shawan and Butler. Dips range from 70 degrees east to vertical.

### SECONDARY STRUCTURES

Later deformation, which affected the gneiss complex, left its traces in abundance. The structures which resulted are found both above and below the unconformity. Unfortunately it is rather difficult to detect and

correct such elements because the entire complex shows such elements throughout. The elements include flow cleavage parallel to the axial planes of folding (pl. II, fig. 2), slickensides, and joints of irregular arrangement and distribution.

Besides striations down the dip of foliation planes, a number of slickensided joints occur throughout the gneiss complex. The striations are rather irregular in the various domes, but seem to be confined to joints striking northeast and east-west. The horizontal projection of the striations is roughly parallel to these joints and their dips gentle to 25 degrees.

## The Unconformity Between the Baltimore Gneiss and the Setters Formation

The unconformity forms the surface of the gneiss complex and the base of the Setters formation. Assuming that this plane was originally horizontal, it now represents in its deformed state a reliable indicator for the degree of minimum deformation, which must also have affected the gneiss complex.

During the post-Glenarm deformation the unconformity has been folded during uplift of the domes and associated anticlines. This folding was on a much larger scale than that in the gneiss complex.

In the circular uplifts with large cores of gneiss the unconformity seems to have been simply domed, while in the more anticlinal structures, as for example, the Phoenix dome and southern half of the Woodstock anticlinorium, considerable folding took place within the uplifts. As a rule, the most intense folding, as well as overturning of the unconformity; has occurred along the southern and southeastern flanks of the domes, as for instance, the Chattolanee, Woodstock, and Towson domes (Plate XXXII).

Southeast of the Woodstock dome the unconformity and Glenarm Series have undergone an intricate folding which has probably obliterated the primary orientation of the dome structure (see Plate XXXII, sections 8 and 9).

Isoclinal folding of the unconformity is confined to the uplift west of the Baltimore, Towson, and Texas domes and eastern half of the Phoenix dome (see geologic map of Baltimore County).

The trend of the unconformity closely follows the outline of the domes and decides their shape. The Setters formation, which parallels the unconformity, shows well its undulations, folding, and overturning.

The trend of primary banding in the gneiss seems to have determined the present trend of the unconformity and all anticlines and synclines and possibly influenced the formation of thrusts (Plate XXXII, sections 4, 5, 9, and 10).

The contour line map (Plate XXVII) shows the normal and overturned attitude of the unconformity. In several cases, where the Setters formation is bounded by gneiss or does not come in contact with it, it was impossible to determine whether it was normal or overturned with respect to the gneiss; as for instance, along the southeastern flank of the Chattolanee dome and west of the Bens Run anticline.

In the Woodstock anticlinorium the overturned isoclinal folding of the unconformity can be seen by the alternating normal and overturned dip of the Setters formation. The eastern flank of the Highland-Alberton anticline is slightly overturned to the east, except in the vicinity of Dorseys Run where it is vertical.

An unusual fold of the unconformity occurs along the periphery of the Woodstock dome one and a half miles northeast of Marriottsville (Plate XXVII). This large fold is clearly shown by the quartzite and its axis seems to strike east-west and plunge gently westward.

## STRUCTURES ABOVE THE UNCONFORMITY

### GENERAL REMARKS

It is assumed in the foregoing that banding, linear structures, and maybe the cross joints in the gneiss are primary structures. However, the arrangement of linear elements in the anticlinal domes parallel to their major axes could be considered as due to a later and superimposed structure which affected the entire Glenarm Series. This deformation produced subparallel larger and smaller folds, the axes of which have a rather uniform trend and remain more or less constant throughout a large area following the major bend of anticlinal axes. On the other hand, the arrangement of structures in the northeastern portion of the Woodstock and Texas domes with their circular arrangement of elements and their blunt endings can hardly be explained by a later regional deformation.

Since these structures are earlier than the deformation of the unconformity it seems highly probable that their arrangement has profoundly influenced the present shape of the domes. Semicircular arrangements resulted in round domes, while general parallel arrangements with consistent strike and only local plunges resulted in long and anticlinal domes; as for example, the Chattolanee and Towson domes.

Before the deposition of the Setters formation the region may have been one of dome-like anticlinal and synclinal units which have been base-leveled and upon which the Glenarm Series has been deposited. It is also possible that this area has been similar to the structures found in the Canadian shield (see Haliburton and Bancroft sheets 1). Here a larger number

of domes and anticlinal gneiss structures with circular and linear arrangements of banding can be seen and are truncated by the present surface.

### SETTERS FORMATION

*Bedding, axes of folding, axes of crinkling, and linear parallelism*

Bedding parallels the unconformity along the flanks and ends of the domes and anticlines (Plates XXVIII and XXIX).

Linear structures roughly conform to those in the gneiss complex, both in strike and pitch (Plates XXX and XXXI). One exception is striking—along the northern flank of the Towson dome between Cromwell Bridge and Notch Cliff where linear structures strike northwest. At Long Green Creek axes of crinkling in the mica schist pitch west while linear parallelism in the gneiss plunges east.

Linear structures in the Setters formation swing around along the rim of round domes; as for instance, the Texas dome and northeastern half of the Woodstock dome. They parallel the flanks of long and narrow domes and anticlines; as for example, the Chattolanee dome and southern half of the Woodstock anticlinorium.

The circular arrangement of linear elements is well shown in the Texas dome (Plate XXXI). Along the south side of the dome they pitch gently west to southwest. Along the northeastern rim of the dome linear parallelism is horizontal, while throughout the north end it strikes and plunges gently northwest. The wide exposure of quartzite here is probably due to the gentle dip of the formation as well as repetition by minor folding. E. B. Mathews and W. J. Miller (75) consider this as due to a large double fold. The axial planes of folds are steep along the south and east sides of the dome while at the north end they seem to dip gently. The axes strike northwest.

Along the periphery of the eastern portion of the Woodstock dome a circular arrangement seems probable because axes of crinkling parallel the rim one mile southwest of Randallstown. Linear structures also follow the north limb of a syncline infolded into the southeastern portion of the dome one mile and a half north of Dorseys Run which may be called the Brice Run anticline. Along the entire western rim of the dome linear elements plunge westward. Their parallelism with those in the gneiss is striking.

In anticlinal domes and long narrow anticlines linear structures parallel the limbs and at their ends follow the axes of uplift. This can be seen in the Chattolanee dome where they roughly parallel those in the gneiss (Plate XXXI). Similar arrangements are found along the limbs of the anticlines southeast of the Woodstock dome (see Plate XXX). Linear

elements parallel the limbs and are either horizontal or pitch gently. At the ends of these anticlines; as for instance between Nicols and Fulton, they maintain their strike and plunge gently down the dip of the Setters formation. In the Bens Run anticline the arrangement of linear parallelism seems to be affected by structures in the Woodstock dome.

Relations in the Towson dome are not as clear but a general parallelism exists with linear structures in the gneiss. The prevailing westward plunge is striking. At the southern end of the dome all linear elements strike and plunge gently southwest.

In the Baltimore dome area axes of crinkling parallel the general strike and plunge of linear elements in the gneiss.

### *Cross joints*

Cross joints in the Setters formation seem to be directly related to and parallel to those in the gneiss. This can be seen in both circular and anticlinal domes (see Plates XXX and XXXI). This relation is best shown in the Texas and Chattolanee domes. In the former cross joints form a radial pattern around the eastern rim of the dome and dip steeply to vertical. They are also abundant at the north end of the dome. In the Chattolanee dome they are vertical and form the major joint system as in the gneiss. Cross joints strike slightly east of north and are vertical near Brooklandville. In the Stone Ridge quarries $\frac{3}{8}$ mile west of Lystra vertical cross joints strike slightly west of north while in Shoemaker quarry $\frac{5}{8}$ mile west of Stevenson they strike northwest and are also vertical. Near Tobin north-south vertical cross joints form practically the only joint system. At Waters quarry $1\frac{1}{4}$ miles east of Pikesville a major system varies in strike from 150 to 20 degrees. From the strike and pitch of linear parallelism it seems likely that cross joints strike 10 to 20 degrees and dip 50 to 60 degrees west. North-south steeply dipping cross joints are abundant in the small quarry $\frac{3}{8}$ mile southwest of Mount Wilson.

In the Towson dome cross joints do not seem to dominate over other systems. In the Rustic quarry near Oakleigh (fig. 25) those joints which strike northeast and dip 60 degrees may be cross joints, judging from the strike and pitch of linear structures. Likewise, at Cromwell Bridge (fig. 26) cross joints should strike northeast and dip 50 degrees east. At Long Green Creek north-south vertical joints seem to be cross joints. Along the southeast flank of the dome cross joints which strike northwest are locally common. At Gunpowder Falls the vertical system which strikes northwest and dips steeply northeast seems to represent cross joints.

A radial arrangement of cross joints around the eastern rim of the

Woodstock dome is indicated by many joints 1 mile southwest of Randallstown. Along the western flank of the dome cross joints bend around from a north-northeast direction on the north to north-northwest on the south. At Blunt's quarry near Hernwood Post Office a very prominent

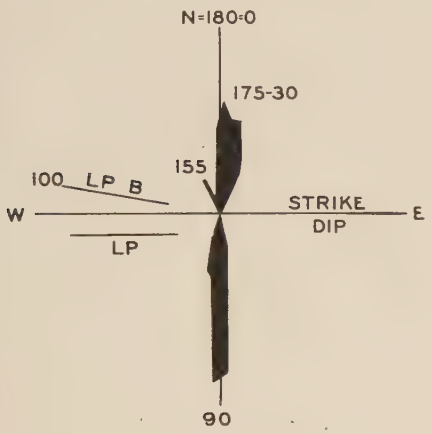


FIG. 23

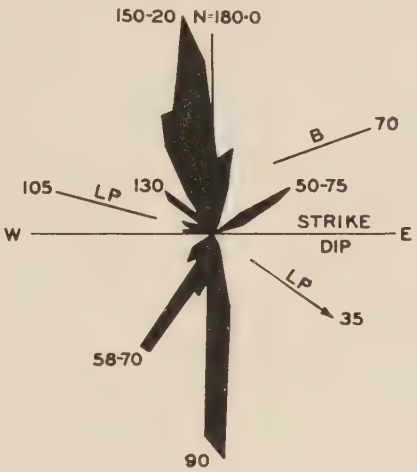


FIG. 24

FIG. 23.—Joints in Setters quartzite. Quarry one-quarter mile east of Tobin.
FIG. 24.—Joints in quartzite. Waters quarry.

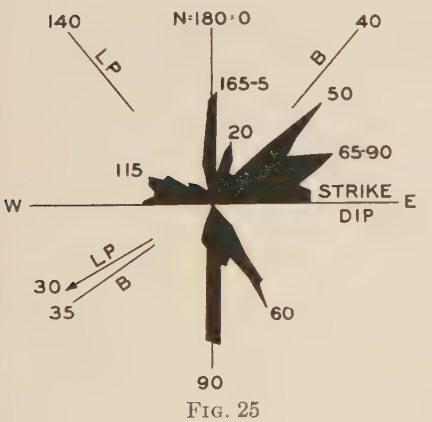


FIG. 25

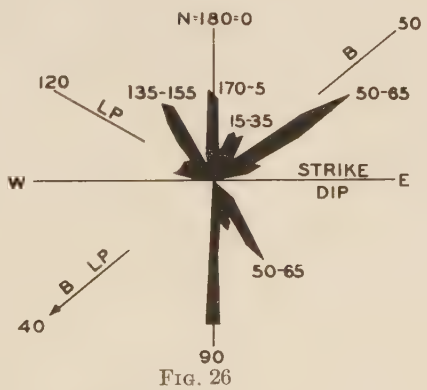


FIG. 26

FIG. 25.—Joints in quartzite. Rustic quarry.
FIG. 26.—Joints in quartzite quarry at Cromwell Bridge.

vertical system strikes north-south. One-quarter of a mile west of Knopf's quarry vertical cross joints strike 10 to 25 degrees. Three-eighths of a mile southwest in Jones' quarry a major system varies in strike from 165 to 25 degrees and dips steeply east to vertical. This system represents in

part cross joints because a faint linear parallelism pitches 25 degrees west. At the Patapsco stone quarries at the North Branch of the Patapsco River relations are clearly defined since good axes of folds and strong linear stretching occur. Cross joints strike north-south and dip 60 to 70 degrees east. At Flynn's quarry, $\frac{1}{4}$ mile northeast of Marriottsville cross joints strike north-northeast and dip 60 to 75 degrees east.

Cross joints are very abundant along the limbs of the narrow anticlines southeast of the Woodstock dome between Alberton and Davis. They range in strike from north to northeast and dip steeply to vertical. At Feeney quarry $\frac{1}{8}$ mile southeast of Davis a dominant north-south system which dips steeply east probably represents cross joints.

Flow cleavage parallel to the axial planes of isoclinal folds is common throughout the area. It is conspicuous in only one locality.

Fracture cleavage in the quartzite was observed only along the north limb of the Towson dome at Long Green Creek, along the northeast side of the Texas dome, and south of Phoenix. In these localities the cleavage planes dip gently to horizontal.

#### THE COCKEYSVILLE MARBLE

Bedding in the marble parallels that of the Setters formation along the flanks of domes and anticlines but in the broader synclines no relation seems to exist for it is frequently on end and is folded independently. However, linear structures parallel those in the Setters formation. Along the southeast flank of the Chattolanee dome axes of folding strike east-west and pitch gently east. The same conformity is seen along the northwest rim of the Woodstock dome, in the syncline west of Clarksville and along the east and south sides of the Texas dome.

Cross joints are prominent along the southeast flank of the Chattolanee dome. They strike 160 to 180 degrees and dip steeply west. Steeply dipping cross joints which strike northeast are common in a quarry $\frac{1}{2}$ mile southwest of Alberton.

#### THE WISSAHICKON SCHIST

Axes of folding, cross joints, and axes of crinkling in the schist largely conform to structures in the above rock types. An exception was noted $\frac{3}{4}$ mile east of Alberton where axes of crinkling strike north-south and pitch gently north.

### STRUCTURES IN IGNEOUS ROCKS WHICH PENETRATE THE UNCONFORMITY

All igneous rocks occurring in the region with the exception of the Hartley augen gneiss penetrate the unconformity. The Gunpowder granite and the Woodstock granite were studied and will be discussed below.

### THE GUNPOWDER GRANITE

Throughout the northeastern portion of the Towson dome the Gunpowder granite has intruded the Baltimore gneiss and Hartley augen gneiss as well as the quartzite and schist along the southeastern flank. "Lit-par-lit" injection prevails although locally cross cutting relations

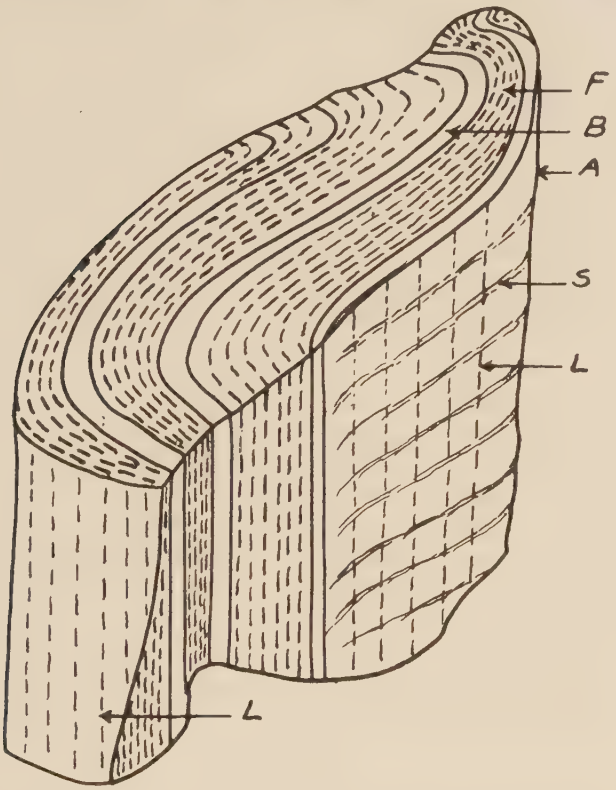


FIG. 27.—Structural elements in folded ribbon gneiss near Clarksville. The horizontal plane is a cross joint. F = foliation, B = banding, A = axis of folding, S = slickensides, L = linear stretching. The horizontal plane is a cross joint.

occur. Along Gunpowder Falls near Harford Road the granite is locally folded along with the quartzite, and schist with flow cleavage is developed. Granite gneisses which appear in the central portion of the Texas dome have been considered as Gunpowder granite by Knopf and Jonas and others. The writer believes that a part of the core is Baltimore gneiss and Hartley augen gneiss as shown by exposures along the periphery.

### THE WOODSTOCK GRANITE

A slightly metamorphosed granite has intruded the Baltimore gneiss and Glenarm Series in the northern portion of the Woodstock anticlinorium between Hernwood and the Old Frederick Road. The intrusive in the center of the Woodstock dome is the only large body. Hundreds of small dike-like bodies of granite intrude the Baltimore gneiss and Setters quartzite in the vicinity of Dorseys Run. The dikes are largely concordant although locally they cut across the foliation and include fragments of the gneiss (Pl. XXV, Fig. 2). In the Setters quartzite and Wissahickon schist they are mostly concordant. Two narrow dikes of granite cut the quartzite, one at Blunt's quarry and another at Jones' quarry. South of Dorseys Run a series of small and larger dikes of granite parallel the strike of the schist. In the larger dikes the schist forms inclusions in or interfingers with the granite. Locally, numerous fragments of mica gneiss occur within a complex of schist and granite resembling what Sederholm called eruptive breccias.

### THE INTRUSIVE AT GRANITE

In the southwestern portion of this intrusive several large areas of Baltimore gneiss with irregular trends were found. Because of the parallelism of linear structures in the areas with that of the country rock (gneiss) it seems likely that they are in place and the granite has intruded around them. The northwestern and southern contacts of the body conform to the general trend of the surrounding gneiss while its eastern and western contacts seem to be intertongued with it. A long arm of gneiss penetrates the southwestern portion as far east as Granite.

Foliation in the granite seems to strike prevailingly eastward and dip moderately north throughout the greater portion of the intrusive. This trend seems to conform to that in the surrounding gneiss and indicates a sheet-like body which dips northward.

Flow lines strike west-northwest and pitch moderately in the same direction (20 to 50 degrees) in the southwestern portion of the intrusive; as for instance at Fox Rock quarry $\frac{1}{4}$ mile west of Granite. Several hundred joints were measured in the Fox Rock and Walkersville quarries as well as other small openings in an attempt to determine the joint system. It was found that no regularity existed. Joints varying in strike from north to northeast were most abundant and consistent. These joints roughly coincide in strike with that of cross joints in the surrounding gneiss. They dip, however, steeply west to vertical and show no relation to the flow lines in the granite.

Linear parallelism in the areas of gneiss within the intrusive strikes

prevailingly west-northwest and dips gently in the same direction. Along the contact of these areas gneiss xenoliths occur in the granite; as for example, $\frac{1}{8}$ mile northeast of Fox Rock quarry. Linear parallelism in the xenoliths strikes west-northwest and pitches 10 to 15 degrees west thus coinciding with flow lines in the granite. Linear elements in a small inclusion of gneiss along the west wall of the Fox Rock quarry also strike west-northwest and pitch 25 degrees west.

### DIABASE DIKES

These dikes are the youngest intrusives in the region and are considered Triassic. They follow the trend of jointing characteristic of this period. Only one exposure was found, $\frac{3}{4}$ mile east of Davis. The dike at this point was 30 feet wide and its strike 15 degrees and dip 75 degrees east. From the distribution of diabase boulders it seems that all of the dikes trend roughly 20 to 30 degrees in the Chattolanee and Woodstock domes.

From the marked coincidence in the trend of these dikes in the vicinity of Dorseys Run and the western end of the Chattolanee dome with that of cross joints, it seems likely that they have in part followed this direction.

## FAULTING

### RUXTON FAULT

Normal faults, which transect the unconformity, the gneiss complex, and the Glenarm Series, belong to the youngest structures of the region. The Ruxton fault, which can be traced from Mount Washington to the northwest end of the Texas dome, was traced by E. B. Mathews in 1904. (See geologic map of Baltimore County). It is considered by Mathews, Knopf, and Jonas to be a thrust which dips east and along which the Towson and Texas domes have moved westward and partly overridden the marble and Wissahickon schist. Their conclusion is based on the general structural relations within the Piedmont, the apparent abnormal thickness of the marble at Lutherville, and the lack of certain formations; as for instance, quartzite and marble. This thrust was projected from Baltimore to the southeastern flank of the Phoenix dome.

The writer is of the opinion that the Ruxton fault is a normal fault for reasons elaborated below:

The fault is accompanied by a breccia which is locally exposed along the western ends of the Towson and Texas domes. Near Hollins Station this breccia dips west at angles varying between 60 and 80 degrees. It can be traced here with interruptions for approximately a half mile. East of Texas it also dips 60 degrees west.

The fault parallels cross joints in the Baltimore gneiss. In the vicinity of the fault these joints are very numerous and have a persistent strike and steep to vertical dip. The fault seems to follow an old pre-existing direction.

A well drilled immediately east of the fault near Lake Station remained in gneiss to a depth of 3200 feet, thus indicating a normal fault. Another well at Lutherville encountered 3000 feet of marble which is an abnormal thickness for this formation. This may, however, be due to an abnormal accumulation of marble due to folding. Experience in the entire region shows that the Cockeysville marble varies greatly in thickness.

Slickensides on a joint plane parallel to a banding in the breccia one mile east of Texas dip west and indicate a downward movement of the western block in relation to the Texas dome.

In a preliminary report E. Cloos described radio reception experiments near Riderwood. He found that the fault occurs in two steps and dips steeply. Since gently dipping contacts or boundaries did not result in radio reception disturbances he concluded that the fault is a steeply dipping normal fault.

The relation of the fault with the axes of the domes, minor axes of folding within the domes, and cross joints indicated that it is probably of the nature of a large cross fault. In many regions in which thrusting and faulting occurs thrusting seems to follow the major axes of folding and parallel the regional strike. Faults which occur in the same regions cross the regional strike as is shown in the Jura Mountains. Examples of this relationship can be found in hundreds of overthrusts in the Alps; the Moine thrust; the Scandinavian thrust; the thrusts in the southern Appalachian region, and maybe the Martic overthrust. Normal faults, which are found in the same area, transect the thrusts at large angles and in many cases are younger.

### LOCAL FAULTS

The occurrence of breccia in other localities; as for instance, the south flank of the Chattolanee dome combined with the interruption of the normal trend of the Setters quartzite, lead the writer to the belief that normal faulting is common (Plate XXXI). The lack of good exposures made a thorough investigation impossible.

Good evidence of faulting was observed in the diabase belt in the vicinity of Dorseys Run. Here the quartzite ridges seem to be offset several hundred yards or more at several localities. This is well shown $\frac{3}{4}$ of a mile west of Wrights Mill Road along the north limb of the Brice Run syncline and $\frac{3}{8}$ of a mile west-southwest of Dorseys Run along the south limb of the Highland-Alberton anticline. No attempt was made to

represent these offsets in Plates XXXII and XXVIII. These two displacements parallel the diabase dikes and may be due to Triassic faulting. The ridges are offset to the south on the west side of this break. A similar offset of quartzite seems to occur near Dorseys Run along the north limb of the Highland-Alberton anticline.

### THRUSTING

The cross sections and maps (Plates XXVIII–XXXII) show clearly that thrusting occurs in many parts of the region, especially in closely folded anticlines and synclines. Minor thrusts may account for relations between Setters quartzite and marble in sections 4, 5, 9, and 10. In nearly all these localities the quartzite is flanked by marble within sharply folded synclines. The writer believes that the quartzite is here thrust over the marble. The distribution of different formations of the Glenarm Series along the flanks of anticlines indicates thrusting of a similar type; as for instance, the southeastern flanks of the Towson dome and Woodstock anticlinorium where the marble and the Setters formation are partly lacking. In all cases the strike of the thrusts is parallel to the general strike of the region and may have resulted from sharp overfolding.

Thrusts seem to be confined to the southeastern and southern flanks of uplifts. This indicates forces in a southeast-northwest direction and may result from movement against the more rigid and resisting gneiss domes.

The rapid thinning of the quartzite ridges to the east along the southeastern flank of the Chattolanee dome seems to indicate thrusting. It is also possible that the south limb of the Mount Wilson syncline is a thrust, since the Setters formation shows a normal width and marble seems to be locally absent. However, this structure was interpreted as a sharp fold in Plate XXXII section 6.

Some thrusting is necessary to explain relations at the southern end of the Bens Run anticline as well as south of Alberton.

The apparent absence of marble in many of the narrow overturned anticlines and synclines southeast of the Woodstock dome may be due to thrusting or squeezing out of the marble.

## METAMORPHISM AND DEPTH OF FORMATION OF THE DOMES

There appears to be a definite relation of metamorphic intensity in relation to the domes and igneous intrusions. The Baltimore gneiss with its crystalline texture shows the maximum intensity of metamorphism, having been produced by dynamic metamorphism modified by contact action of igneous injection at considerable depth. Knopf and Jonas (64) point out that the high degree of metamorphism of the gneiss shows no

evidence that it is the result of several periods of metamorphism, having remained inert since its formation due to its prolonged deep-seated position. The lower formations of the Glenarm Series including the quartzite, marble, and eastern facies of schist show a high degree of metamorphism while the upper formations of the Glenarm Series, the Peters Creek formation, in the Peach Bottom syncline as well as the western facies of schist show less metamorphism. Knopf and Jonas consider this situation as due to diapthoritic changes. The difference in intensity between the eastern and western facies may be explained by the numerous igneous intrusions in the former facies which may have produced a regional contact metamorphism. Also the eastern facies may be at a deeper level of erosion than the western facies. The intrusion of a large body of granite (Sykesville granite) in the Peach Bottom syncline has, however, not increased appreciably the degree of metamorphism of the sediments.

The problem of the highly metamorphosed sediments which surround the Mine Ridge anticline in Pennsylvania contrasted with the low intensity in the Glenarm formations to the south lead Knopf and Jonas (65) to the conclusion that the dominant metamorphism in both Paleozoic and Glenarm strata was subsequent to an overthrust which brought the Glenarm Series over the Paleozoic sediments (Martic overthrust). They state that depth of burial with load metamorphism alone is insufficient to produce crystalloblastic textures. They suggest a rise of geothermal gradient from an igneous source and together with the increased load of the overthrust block would be sufficient to account for the high metamorphism of the Paleozoic rocks.

It seems more likely to the writer that this difference in degree of metamorphism is a function of the depth of formation of these structures previous to uplift in the eastern portion of the Piedmont.

## SUMMARY AND CONCLUSIONS

As a general rule the axes of major and minor folds are parallel in the entire region. In spite of this fact these structures can not be ascribed to the same period of deformation. The folds in the Baltimore gneiss complex seem to determine the trend of the domes. In the anticlinal domes the axes plunge towards their ends and parallel their flanks, roughly outlining the trend of the domes as primary structures. The shape of the domes, however, is superimposed on the older structures which have been formed before the Setters quartzite has been deposited. The blunt endings of circular domes and the semicircular arrangement of internal dome structures strongly suggests that the superposition of post-Glenarm doming was guided by earlier structural lines.

The semicircular arrangement is followed by the structures in the marble and Wissahickon schist which run around these blunt ends. In this way the structure of the marble and schist seem to parallel the structures in the gneiss. Considering the major axes of uplift, the minor structures in the marble and schist cross these axes at right angles.

The presence of the unconformity between the Baltimore gneiss with its primary structure and the Glenarm Series which have suffered from later periods of deformation renders a simple connection between the two units unlikely. The deformation of the Glenarm Series may have affected the Baltimore gneiss complex only to the extent of intensifying the older dome structures.

The deformation of the unconformity, to which the Setters formation seems closely attached, is of very much larger order of magnitude than minor folding in the gneiss complex below or in the marble and schist above. Major folds are overturned toward the north as well as to the south and toward the west as well as to the southeast. This lack of a uniform direction of folding and movements renders a simple explanation difficult.

The writer believes that an explanation of the structures in the crystalline rocks of Maryland and probably of the Piedmont in general hinges on a consideration and careful study of the Gneiss-Glenarm unconformity and its deformation. Uniform movements seem to comprise all formations above the Setters quartzite. The relatively incompetent Wissahickon schist is closely folded but its formational boundaries probably dip gently. Its flow cleavage is steep and its fracture cleavage seems to dip uniformly northwest over a large area. Fracture cleavage developed in the Setters mica schist is probably directly related to this fracture cleavage in the Wissahickon schist complex. The deformation of the unconformity and the attached Setters indicate folding by bending. The shear planes have never been observed to penetrate the unconformity or the Setters formation. It is therefore most surprising to observe the lack of uniformity in folding between the major folding of the Baltimore gneiss surface and the Setters formation in contrast to the prevailing minor folding of the marble and Wissahickon schist. The writer believes that the only explanation for this discrepancy lies in a deformation of the marble and schist which affected only comparatively slightly the gneiss complex and Setters formation. In this deformation the latter seems to have been protected and its deformation guided by its close connection with the gneiss. It is only in a few localities that the quartzite leaves its position as the next neighbor of the gneiss; for example, where thrusts may be present.

It seems possible that the deformation of the Wissahickon schist found its lower limit approximately in the very incompetent marble which

facilitated the separation of the schist from the competent gneiss-quartzite unit. This would explain the discrepancy between the typical minor folding in the incompetent marble-schist unit and major folding of the gneiss surface and quartzite. The relative competence and incompetence of formations is therefore an important factor.

During the folding of the unconformity the marble may have acted as a lubricant for the close folding of the Wissahickon schist. The intense deformation which must have accompanied uplift of the gneiss surface and the closely attached Setters formation might explain the considerable variation in thickness and frequent absence of the marble. Its relative incompetency would explain the discrepancy in type of folding above and below the unconformity.

Conditions may have been similar to the folding of the Swiss Jura above the Triassic. Here Triassic salt beds have obviously served as a lubricant during a rather shallow folding process (51). Since there is no uniform direction of overturning and folding within the gneiss domes, the writer does not believe that a uniform pressure through thrusting could have produced these structures. The older internal structure of the gneiss domes in combination with igneous intrusions may have influenced their formation.

The oval to almost circular outline of the Woodstock and Texas domes makes the introduction of vertical uplifting forces almost inevitable. Lateral compression alone could not explain the semicircular arrangement of structures which run around these domes. Such structures are most abundant in all regions in which one considerable vertical component of uplift or subsidence is proven; as for instance, in all laccolithic and many batholithic domes as well as in basins and depressions. The writer, however, does not intend to infer a batholithic origin for the gneiss domes.

The lack of any uniform overturning of the gneiss domes and associated anticlines seems to argue against large overthrusts. The general relations indicate local thrusting associated with the gneiss domes during deformation of the unconformity.

The writer believes that the shape of the domes has been determined by pre-Glenarm structures and that they have been partly upfolded and partly upthrust into the Glenarm Series during post-Glenarm deformation. Normal cross faults and cross joints transgress the major and minor axes at large angles while reverse faults and thrusts parallel these axes and are confined to the flanks of the domes and associated anticlines. The gneiss complex and Setters quartzite may have taken an active part in the production of thrusts while the marble and schist appears to have played a passive rôle in the deformation of the region.

LOCATION OF CROSS SECTIONS

(On plate XXXII)

Towson dome:

1. Long Green Creek.
2. Gunpowder Falls.
3. Western portion of dome.

Chattolanee dome:

4. Green Spring Avenue
5. Three-quarters of a mile west of section 4.
6. Section through Tobin and Mount Wilson.
7. Western portion of dome.

Woodstock anticlinorium:

8. Harrisonville to Old Frederick Road.
9. From Dogwood Road through Alberton to Sucker Branch.
10. From Brice Run across Bens Run Anticline
11. From Henryton to ¾ mile southeast of Davis.
12. From Alpha to 1 mile south of Pine Orchard.
13. One-half mile north of Carrolls Mill.
14. One mile north of Clarksville.

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*Maps*

(115) Topographic and Geologic Survey of Pennsylvania. Map of Pennsylvania showing the Geological Formations. 1931. 1: 380, 160.
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(120) Virginia Geological Survey. Map of Virginia showing the Geological Formations. 1928.

# VITA

Carl Huntington Broedel was born in Baltimore on the seventh of June, 1908. He received his elementary and high school education in the public schools of Baltimore and entered the School of Arts and Sciences at the Johns Hopkins University in September, 1926. He obtained his A.B. degree in 1931 and was admitted to the Department of Geology in the fall of the same year. Since that time he has been in residence as a graduate student.

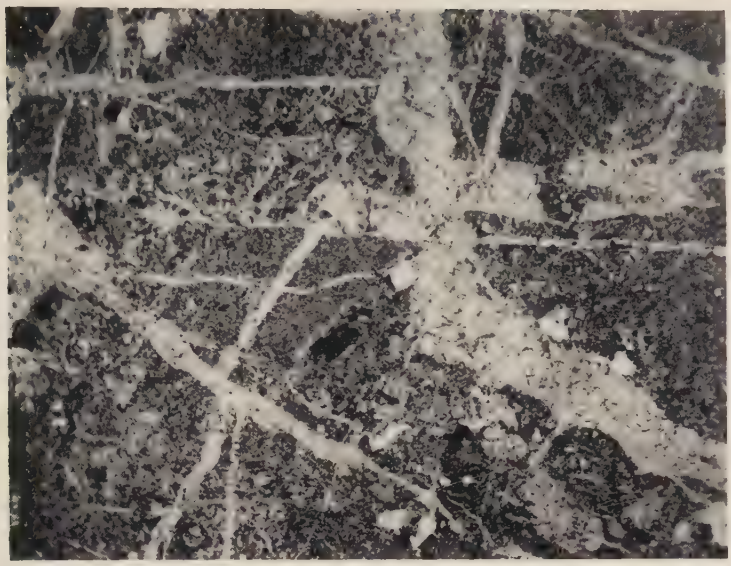

FIG. 1.—Fault Breccia from Lake Roland northwest of Baltimore. Photomicrograph. Approx. × 15.

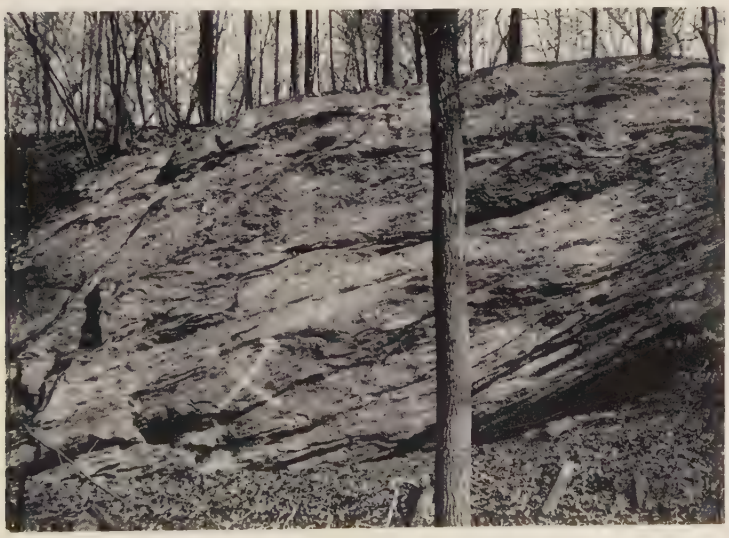

FIG. 2.—Foliation and gently dipping axes of folding in Baltimore gneiss. North Charles Street, one and a quarter miles southeast of Ruxton.

FIG. 1.—Cross joints intersecting linear structures at an angle of 90°, Western Maryland Railroad cut at Lyons Mill Road.

FIG. 2.—Crinkled Setters schist showing axes (parallel to hammer handle) pitching gently west. Long Green Creek.

FIG. 1.—Large isoclinal fold of Setters quartzite pitching gently west. Hammer handle parallels the axis of the fold; arrows in chalk indicate linear grooving. One and a quarter mile northeast of Marriottsville, Maryland.

FIG. 2.—South limb of Jew Bottom anticline, looking east near Brice Run. The quartzite dips gently north. Cross joints (in shadow) strike N–S.

FIG. 1.—Vertical bedding in Setters quartzite. Horizontal fracture cleavage parallel to hammer head. One and a half miles northeast of Warren.

FIG. 2.—Inclusion of Baltimore gneiss in aplite granite. The banding in the gneiss xenolith parallels that in the adjacent gneiss. Three-eighths mile northwest of Dorsey's Run.

FIG. 1.—Inclusion of Wissahickon schist in Woodstock granite. One-half mile Southwest of Dorseys Run.

FIG. 2.—Strong linear parallelism in Baltimore gneiss. One-half mile east of Alberton.